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DUST EXPLOSION PREVENTION IN TERMINAL GRAIN ELEVATORS.

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Introduction

The Bureau of Agricultural Chemistry and Engineering, which I have the honor to represent at this meeting, is engaged in scientific research studies relating to chemical and engineering problems connected with explosions and fires in the handling, milling, processing, and storage of agricultural products. In this research work on explosion and fire prevention our Bureau has cooperated very closely with the agricultural industries directly concerned and with the fire departments in the handling of fire-fighting operations in connection with these industrial plants. A very pleasant and helpful relationship has been established with these industries, fire departments, and fire prevention associations, safety and insurance organizations and State and Federal agencies. Among the national organizations cooperating in this explosion and fire prevention work are the National Fire Protection Association, National Safety Council, International Association of Fire Chiefs, International Association of Fire Fighters, National Board of Fire Underwriters, National Fire Waste Council, Western Actuarial Bureau, American Standards Association, and a number of other national organizations interested in the fire and explosion prevention movement.

This direct contact with these organizations affords a ready means of translating into actual practical use the results of technical research on dust explosion prevention, and it is therefore especially pleasing to have an opportunity to present some of the developments in this research work to representatives of the grain-handling industries.

(I) Research Work on Dust Explosion Prevention

The Federal Government has conducted extensive research studies to determine the causes of dust explosions and to develop methods for their prevention and control.

The Bureau of Mines, U. S. Department of the Interior, has definitely established the fact that explosions can occur in bituminous coal mines without the presence of explosive mine gases, and that the ignition of the coal dust itself has been responsible for many disastrous mine explosions. As a direct result of effective research work by that Bureau methods have been developed for the use of inert dusts, such as shale, limestone, and gypsum, for the control and prevention of coal dust explosions. Reports issued by the Safety Section of the Bureau of Mines indicate that these methods have proved very satisfactory.

The studies of the Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture, show that under favorable conditions a dust explosion can occur in any industrial plant or manufacturing establishment where combustible dust is created during manufacturing operations. When these research studies were undertaken it was generally supposed that it would be necessary to grind or crush grain and produce the powdery

starchy materials from the inside of the grain before an explosive dust would be encountered. This was largely due to the fact that an explosion of flour dust produced in the manufacture of wheat flour in a Minneapolis mill in 1878 caused the loss of 18 lives and extensive property damage. A large number of explosions in grain elevators, where no grinding or manufacturing operations were engaged in, showed definitely that the dust produced in the handling, elevating, conveying, and storing of grain also was explosive.

A survey has shown that the dust explosion hazard exists in a wide range of industries, such as flour and feed mills, grain elevators (both terminal and rural), starch factories, sugar refineries, woodworking plants, powdered milk plants, soap powder factories, sulphur crushing and pulverizing, hard rubber recovery plants, cork pulverizing plants, chocolate and cocoa plants, paper mills, insecticide plants, celluloid and textile plants, aluminum, zinc, and magnesium plants, fertilizer plants, and rosin-handling plants.

We find, therefore, that approximately 28,000 industrial plants in the United States are subject to the dust explosion hazard. These plants normally employ 1,325,000 persons and manufacture products having an annual value of more than ten billions of dollars ($10,000,000,000).

(II) <u>"Oatmeal Explosion" - 1888</u>

The public is always interested when a new kind of "mysterious industrial explosion" occurs; therefore an explosion in an oatmeal mill in Chicago on December 11, 1888, aroused unusual interest. Reports state that this explosion was heard several miles away and "hundreds of people were awakened, many of them thrown from their beds."

This explosion provoked considerable discussion in the popular press, all centering on the possibility of an "oatmeal explosion." One of the Middle West papers seemed much concerned over the fact that "this is the first time it has been suggested that oatmeal has volcanic properties, its worst characteristics in the popular mind being its disposition to irritate the skin and set a man to rubbing his back against the door jamb."

The paper saw some humor, however, in this new "oatmeal dust explosion" theory, intimating that if it was found that oatmeal was explosive, then a good many mysterious disappearances might be accounted for. It referred to the disappearance of an Ohio town treasurer as follows: "He was last seen on his way to the village through an open field, soon after breakfast. It was supposed that he took the cars at another station and had fled to Canada. The words 'soon after breakfast' may be full of significance, and the suspicion of the honesty of the man may be cruelly unjust. Everyone in Ohio eats oatmeal for breakfast, and it is among the possibilities that this town treasurer exploded on his way to town and that he did not go to Canada, excepting, perhaps, a few pieces of him."

Similar comment was made by the press throughout the country, and the possibility of a "breakfast food" exploding was responsible for many humorous

newspaper accounts. The following is typical: "Until the question is definitely settled whether oatmeal is explosive, people should be a little more cautious about riding down town in a morning street car with any Scotch fellow citizen. No man can tell how many bombs are walking about the streets filled with the dynamic force of an oatmeal breakfast. While we are feeling gay in fancied security, we may at any moment be blown higher than Gilderoy's kite by a bowl of oatmeal mush."

One of the Southern papers saw alarm in the situation and commented as follows: "The explosion of the oatmeal mill in Chicago probably will cause a decline in the use of that hygienic article of food. No man is going to risk an explosion in his abdominal regions simply because a doctor tells him that oatmeal is healthy."

(III). Theory and Nature of Dust Explosions

From the research work on this problem, it is now generally accepted that in theory a dust explosion is somewhat similar to a gas explosion. The dusts require definite ignition temperatures and also have what may be termed the lower and upper limits of concentration for explosion. For example, methane gas (mine gas), CH_4, to be explosive, requires a mixture of 5.5 percent gas and 94.5 percent air, which we term the lower explosive limit. When the mixture contains approximately 10 percent of this gas and 90 percent of air, the explosion is most violent. When the gas is increased to about 15 percent with 85 percent of air, the mixture becomes non-explosive and cannot be ignited. This is termed the higher limit of explosive concentration. These limits of concentration vary with different dusts as well as with different gases.

The ignition sources of explosive dusts are practically identical with those of explosive gases so that any source which will ignite explosive gases will ignite explosive dust clouds. These sources of ignition include matches, open flames, electric sparks and fires.

One of the principal factors in the explosibility of dust appears to be the degree of fineness of the dust. The explosion appears to result from the propagation of flame through a finely and uniformly divided dust cloud. This flame travels at a rapid speed, building up considerable pressure and thereby producing what we ordinarily call the explosion. It has therefore been extremely difficult in certain instances to determine definitely when the fire ended and the explosion started. It would appear that any fire might result in an explosion if combustible dust clouds are present.

The ignition of an explosive mixture of dust and air results in a primary flash or explosion of limited proportions. The concussion accompanying this primary ignition, however, is sufficient to shake into suspension the dust that has settled, lodged, or accumulated on ledges, beams, girders, machinery parts, and inaccessible points in the plant. The dust forced into suspension in the air in this manner feeds the flame or fire from the first or primary explosion and causes a secondary explosion of larger proportions in which higher pressures are developed and considerable violence results.

The importance of removing the settled or "static" dust in an industrial plant is therefore a vital factor in dust explosion control and prevention. If there is not sufficient dust to permit the primary flash to propagate, the flame gradually dies down, and there is no secondary explosion.

Early Research on Dust Explosions

Some of the earliest work in the United States on explosibility of dusts was carried on by L. W. Peck, instructor of physcis, and Stephen F. Peckham, professor of chemistry, both of the University of Minnesota, after the explosions in the Washburn Mills, Minneapolis. This experimental work done by Peck and Peckham in connection with the coroner's inquest, has been of great value to investigators of this problem in recent years. In a lecture delivered June 1, 1878, at the request of the millers of Minneapolis, Professor Peck demonstrated by a few simple experiments that under proper conditions practically all combustible material, when finely divided, forming a dust or powder, would burn with explosive rapidity.

To enable the coroner's jury to appreciate the violence of the Minneapolis explosion, Peckham informed the jurymen that from a sack of flour weighing 98 pounds and a room containing 4000 cubic feet of air, enough force could be generated to throw a weight of 2500 tons 100 feet high.

(IV) "Dust Engine" Developments

Attention is being directed to research on the possibility of utilizing explosive dusts for power purposes. The early work by Diesel in developing the Diesel motor is of special interest. The research work in the Department of Agriculture on dust explosion prevention has made possible the securing of considerable information on the behavior and action of explosive dust clouds, with particular reference to ignition temperatures, rate of flame propagation, pressures developed and other important factors. This data should be helpful in further research work on this subject. It is planned to give special attention to the development of motor fuels from farm products in the program now being planned for the Northern Regional Research Laboratory of the Department of Agriculture now under construction at Peoria, Illinois. The purpose of this laboratory will be to develop new and wider industrial uses for surplus agricultural crops in this territory.

(V) Factors in Dust Explosion Prevention

The two principal factors in dust explosion prevention in industrial plants are:

(1) Effective measures for control and removal of explosive dust.

(2) Elimination and control of sources of ignition.

Methods for Prevention and Control of Dust Explosions

1. Dust Collection and Removal -

Cleanliness and good housekeeping are of prime importance in dust explosion prevention. It is impossible to handle or clean grain without making dust, but the dust should be collected and removed without being permitted to accumulate in any section of the plant. A dust explosion cannot occur unless combustible dust is present.

2. Removal of Foreign Material from Grain -

Foreign material in the grain has been responsible for several explosions in grain elevators. Investigation of these explosions indicated that the dust clouds had been ignited by sparks from metal particles in the grain. Methods must be developed, therefore, for the effective removal of any metal or other foreign material that may drop into the grain while it is being handled. It is difficult in many instances to prevent foreign material from entering equipment in grain-handling operations, but screens of 1 1/2 to 2-inch mesh placed in the gratings over receiving pits have in many instances stopped large pieces of metal from entering the pits with the grain. The use of such screens and the practical value of magnetic separators in the grain-handling sections of the plant should be given further attention.

3. Inert Gas Protection in Grinding and Pulverizing Operations -

The reduction of the oxygen content of the air in the enclosed system by the introduction of inert gas, such as carbon dioxide (CO_2), in grinding and pulverizing operations has proved effective in the control and prevention of dust explosions. When the oxygen content is reduced to approximately 12 percent in grain-grinding operations, complete protection is afforded. The reduced oxygen content (as the result of the addition of inert gas) prevents the ignition of the dust cloud in the grinding machine, and also prevents the spread of fire through the conveying and elevating machinery.

4. Protection of Electrical Appliances and Equipment -

A study of the causes of dust explosions has shown the danger of inadequately protected electrical appliances and equipment. Electric lamps should be protected with outer dust-proof globes and heavy wire guards to prevent breakage. Portable spotlights of suitable design and construction to be directed into bins through manholes should be used as temporary or occasional lights for bin examination, instead of electric light globes on extension cords lowered into bins. This recommendation is covered in the Safety Code for Terminal Grain Elevators.

5. Control of Static Electricity -

Static electricity must be recognized as one of the prominent causes of dust explosions, and considerable attention has been given to the development of control methods for this hazard. Provision should be made for the removal of static charges on all types of mechanical equipment handling combustible dusts or operating at points in the plant where these dusts are present.

6. Value of Closed Storage Bins -

The value of closed bins and the undesirability of interconnections between storage bins are indicated by explosions in grain-handling plants. Open storage bins and bins with direct connections permit the rapid spread of flame over the tops of the bins and thereby extend the violence of the explosion. Preventing the spread of fire from one storage bin to another is of prime importance.

7. Explosion Venting Areas in Grain-Handling and Milling Plants -

The Chemical Engineering Research Division of the Bureau of Agricultural Chemistry and Engineering has shown that it is possible to vent grain dust explosions without structural damage, and the effectiveness of glass vents in actual explosions has confirmed the tests of the Bureau. In one case the workhouse in a large terminal grain elevator was saved from destruction by an adequate glass venting area. In another case proper venting area to relieve the pressure from an explosion in the workhouse of the elevator would have prevented the complete destruction of the top of the house. Provision for venting dust explosions should be made in the construction of all new grain handling plants. It is recommended that for satisfactory venting of dust explosions in grain elevators not less than 1.25 square feet of venting area be provided for each 100 cubic feet of space (1 sq. ft. to 80 cu. ft.).

(VI) Development of Safety Codes for Dust Explosion Prevention

One of the principal accomplishments in dust explosion control and prevention is the development of safety codes by the Dust Explosion Hazards Committee of the National Fire Protection Association. This committee, composed of representatives from the various industries directly concerned and from insurance and safety organizations, State and Federal officials, and construction and equipment engineers, works under the leadership of the Chemical Engineering Research Division of the Bureau of Agricultural Chemistry and Engineering.

The following safety codes developed by the Dust Explosion Hazards Committee have been adopted by the National Fire Protection Association and

the National Board of Fire Underwriters, and approved as "American Standard" by the American Standards Association:

1. Flour and feed mills
2. Sugar and cocoa pulverizing
3. Pulverized fuel installations
4. Terminal grain elevators
5. Starch factories
6. Coal pneumatic cleaning plants
7. Wood flour manufacturing establishments
8. Spice-grinding plants
9. Wood-working plants
10. Use of inert gas for fire and explosion prevention

These safety codes, published by the Bureau of Labor Statistics of the U. S. Department of Labor as Bulletin No. 562 and supplement No. 617, both entitled, "Safety Codes for the Prevention of Dust Explosions," have been very helpful in the application of measures for the prevention of dust explosions and fires.

Safety codes on the prevention of (1) aluminum and other metallic dust explosions, and (2) dust explosions in the handling, grinding, and storing of sulphur also have been recently prepared by this committee as well as an outline of Fundamental Principles for the Prevention of Dust Explosions in Industrial Plants, not covered by special codes.

(VII) Progress in Dust Explosion Control

Reduction of Losses in Food Industries

It is very gratifying to observe that there has been a marked reduction in losses from dust explosions in recent years, particularly in the food industries.

In the starch and corn products industries, where disastrous dust explosions have occurred, no life has been lost from a dust explosion since September 20, 1930, a period of over nine years. This remarkable record for the starch and corn products industries is a significant indication of the value of the work of the safety organizations in this industry. It shows progress in dust explosion control and prevention.

Losses also have been reduced in flour mills, where disastrous explosions were experienced in the earlier years of this important industry.

We can more fully appreciate the reduction of dust explosion losses in this group of food industries when we realize that during the same period a large number of dust explosions have occurred in other branches of the grain-milling industry, resulting in large losses of life and extensive property damage.

The sugar-refining industry also has established a remarkable record. Not a life has been lost in an explosion of sugar dust since June 13, 1917.

Similar progress has been made in cocoa and chocolate plants and in the grinding of coffee and spices.

Comparison with Grain Elevators

Although losses from dust explosions have been reduced materially in the food-manufacturing industries which have cooperated in working out and adopting practical safety and preventive measures against dust explosions and resulting fires, there is still need for more definite attention to the application of methods for the control and prevention of dust explosions in grain elevators. Since 1930, 56 grain elevator explosions have been reported. In these explosions 40 people were killed, 145 were injured, and the property losses amounted to more than $7,500,000. These 56 explosions were almost 36% of the total number of explosions reported during the period. This is a positiv indication that more definite attention must be given to dust explosion prevention in grain elevators.

Effect of New Manufacturing Processes

Although considerable progress has been made in the United States and Canada in the control and prevention of dust explosions in grain-handling and milling operations, it must be admitted that all possible causes of dust explosions are not positively known. Dust explosions may occur in an industrial plant as a result of some newly developed type of mechanical or electrical equipment. Many of the dust explosions in recent years in the United States have been directly associated with the introduction of new manufacturing processes which have opened up additional sources of ignition and have resulted in conditions favorable to explosions. It is therefore highly desirable that new manufacturing operations be carefully examined to detect possible dust explosion hazards, and that attention be given to the adoption of preventive measures.

(VIII) Dust Explosion in Rosenbaum Grain Elevator Chicago, Ill., May 11, 1939

The dust explosion and spectacular fire in Chicago on May 11, 1939, caused the loss of nine lives, more or less serious injury to about 30 men, and a property loss of about $3,500,000. The initial explosion occurred about 8:52 a.m. in Calumet Elevator A, owned by the Chesapeake & Ohio Railroad Company and operated by Rosenbaum Brothers. The fire which followed spread to Elevator B, also known as Elevator A Annex, and to Elevator C of the Rosenbaum group, and then jumped across a slip and ignited two other elevators operated by the Norris Grain Company. All elevators were located along the Calumet River between 102nd and 103rd Streets. The elevators were built in 1894 and 1895 and were of the old style metal-clad, frame construction with crib bins. The destruction of the five wooden elevators and their contents was almost complete. A section of concrete grain storage tanks along-side Elevator A and portions of brick buildings formerly used for power houses, when the elevators were operated by steam, remained standing. Only a small amount of the grain in storage was salvaged.

Description of Plant

Many changes and improvements had been made since the buildings were constructed, particularly in providing additional fire protection during recent years. Automatic sprinklers had been installed, and provision made for water curtains on the exposed sides of the Calumet Elevators. The Norris Elevators were not provided with sprinklers.

The concrete storage tanks were erected in 1930 and were connected to Elevator A by concrete belt tunnels at the basement level and by steel frame, metal-clad belt galleries at the level of the top of the tanks. Guillotine doors operated by fusible links were provided to prevent the spread of fire through the tunnels.

Electric power had replaced steam power in the elevator plant, and the old boiler equipment had been dismantled. The boiler house was used for shop work and to house the fire pumps. Electrical equipment was probably well above the average, with wires in conduit, vaporproof lights, and dustproof and non-sparking motors. Dustproof switch and fuse cabinets were generally used. Squirrel-cage motors were used in the concrete tank section, and some old style fuse cabinets had not been replaced. Motors were grounded.

Elevators A and B were connected by a steel frame, metal-clad belt gallery for the transfer of grain from one house to another, and Elevators B and C were connected by a concrete belt tunnel for the same purpose.

Equipment in all houses was largely of wood. Scales and garners were of wood. Elevator legs and heads were of wood, but boots were of metal.

A grain drier with brick walls about three stories high was located east of Elevator A. It was connected to Elevator A by several spouts and a frame-enclosed belt gallery or tunnel at the ground level.

A metal-clad, frame dust house located east of the drier also was connected to Elevator A by spouts or ducts from the cleaning floor located about the middle of the bins in the southeast corner of Elevator A. Fans on cleaners, clippers, and separators located in this cleaning room discharged to the dust house. Floor sweeps in Elevator A connected to a fan on the first floor which discharged to the dust house.

East of the concrete storage tanks was a truck dump arranged to receive grain brought to the elevator by trucks. In this sheet metal building was installed equipment to lift trucks and discharge their grain into a hopper connected by conveyor belts with the belts in the basement of the storage tank section. Two of these belts were operating in concrete tunnels.

Story of the Explosion and Fire

Information available indicates that the men had reported for work about 8:00 a.m. and were engaged at their regular duties when the explosion occurred. One elevator employee was in charge of the truck dump,

east of the concrete tanks, where grain delivered to the elevator by motor truck was unloaded. He was seriously burned and died in the hospital the next day. Nine other men were working in Elevator A, eight of whom are believed to have died in the explosion and fire. One employee escaped, but he was seriously burned and had been caught under falling debris at the east end of Elevator A. He was rescued by workers from other parts of the plant and taken to the hospital. Two bodies were recovered and identified. Parts of other bodies were recovered, but at the time this report was prepared all had not been identified.

From the superintendent of the elevators, the foreman and the employee who escaped, information was obtained concerning the operations in progress in Elevator A at the time the explosion occurred. Neither the superintendent nor the foreman was in the elevator at the time, but they described the operations they believed were being carried on. These operations may be described as follows:

1. The day before the explosion occurred several truck loads of corn arrived at the elevator. All but one had been unloaded on the truck dump east of the concrete tanks by quitting time. When operations were resumed the next morning six elevator legs -- Receivers 1, 2 and 3, and Shippers 3, 4 and 5 -- were started in Elevator A; the conveyor belts from the truck dump to the basement of the concrete tanks and through the tunnel to Shipper 4 were started and the truck load of corn held over from the day before was emptied. This corn traveled over the conveyor belts to the boot of Shipper 4, was elevated, weighed and spouted to a bin. As far as is known, no distributing belts were operating in Elevator A. This particular grain handling operation had been completed prior to the explosion, because the information available indicates that the trucker, after unloading at the dump, drove to the elevator office where he was advised of the weight and had left the premises.

The elevator employee in charge of the truck dump had shut down the conveyor belt leading from the dump into the concrete tank section and had entered the basement of the tank section to shut down the belt which carried the grain through the tunnel to the boot of Shipper 4 in the basement of Elevator A. His statements before he died and the evidence available indicate that he was at a point under the tanks along the north side and about one-fourth of the length of the basement from the east end. Rescuers found him on the roadway along the north side of the tanks, and he indicated to them that he had just shut down the belt leading to Shipper 4 when the explosion occurred, and that he had climbed out of one of the basement windows. The condition of the conveyor belt noted by the investigators indicated that it had been stopped before the explosion occurred. The control button for this belt was along the north wall of the tanks, where the employee stated he had been standing. He evidently selected the basement window as the quickest means of escape from the building when the explosion occurred and enveloped him in flames.

2. On the day before the explosion some wheat was transferred from Elevator B to Elevator A and a part of this lot of grain was held in the upper cleaner bin. As described previously, the cleaning room was located about halfway between the ground floor and the top of the bins

at the southeast corner of the bin section; the portion of the original bin above this room was known as the upper cleaner bin, and the portion below the room was known as the lower cleaner bin. At the time the explosion occurred the grain which had been held for cleaning was being run through the cleaner into the lower cleaner bin, and from it to the boot of one of the shippers which elevated it for distribution to designated bins. The bin foreman was the man who arranged for the distribution of this grain to a designated bin, and he is listed as one of the men killed in the explosion. Information concerning the arrangements for this grain transfer was not available to the investigators. Information concerning the shipper leg used to elevate the grain from the cleaners was confusing. It was indicated that either Shipper 3 or Shipper 5 could be used and both were running.

3. Some sweeping was being done at the southeast corner on the first floor of Elevator A. The foreman stated that when he passed through the first floor of Elevator A a few minutes before the explosion, on his way from the office building west of the elevator to the millwright's shop, located between Elevators B and C, two of the employees were sweeping or cleaning up around Shipper 5. The statement of the employee who escaped from this section of the plant checks with this information. He advised the investigators that he was sweeping on the east side of Shipper 5 and another employee was sweeping on the west side of the leg. He stated that the first flash of fire came out of Shipper 5. It is assumed that one shipper leg was used to elevate the clean grain from the cleaning operation described under 2, and another leg was used to elevate the screenings from this operation and the material swept up on the first floor.

Operations in other sections of the plant, particularly Elevators B and C, had no bearing on the cause or origin of the explosion. Although some grain-handling operations were in progress in these houses, the explosion did not propagate to them. and it was some time before they were ignited by the fire which followed the explosion in Elevator A.

Some repair operations were in progress in the drier building directly east of Elevator A, but the two men engaged in this work escaped without being burned or injured.

The dust house located east of the drier was not involved in the original explosion. One man was at work in the building, according to information furnished the investigators, and he escaped without injury.

There was evidence to indicate that the explosien propagated from the basement of Elevator A, through the tunnels to the basement of the concrete tanks, and upward through the steel leg and its concrete enclosure at the east end of the tanks.

Origin of the Explosion

From the evidence obtained in an inspection of the ruins and statements of employees, it is believed that the explosion originated in the boot of Shipper 5. This leg may have been handling screenings from the cleaners. The fact that the men on the first floor were sweeping into this boot would indicate that a certain amount of dust was present in the leg.

The tunnel through which the conveyor belt ran from the basement of the concrete tanks to the boot of Shipper 5 was examined as far as possible from the tank end and was found to bear more evidence of fire than could be noticed in other tunnels. Charred dust on the curved concrete wall where this tunnel entered the tank basement indicated that the flames propagating from the basement of Elevator A were deflected toward the east end of the tanks, where they entered the steel leg and its concrete enclosure. Of course there was some flame propagation in other directions, but the evidence would indicate that the principal paths of travel were northward through the tunnel from the boot of Shipper 5, westward through the first floor of Elevator A, and upward to the cleaner room and through the leg to the upper floors of Elevator A.

Possible Causes of the Explosion

Although there was considerable evidence that the cause of this explosion may have been associated with the unloading of the truck load of corn at the truck dump east of the concrete tanks, it was not possible to establish this operation as the most probable cause. It was assumed that foreign material in the corn might have caused a spark when it entered the conveying and elevating machinery. It was suggested also that the truck in starting may have backfired and ignited dust which fell on to the conveyor belt and was carried into the elevator. Electric sparks from the motors or starters on the conveyor belts from the truck dump also were cited as possible causes. The fact that the truck dumping operations had been completed sufficiently long before the explosion occurred to permit the weighing of the load and the delivery of the weight ticket to the driver at the office, and the fact that he had left the premises precluded the establishment of these possible sources of ignition as the most probable cause of the explosion.

The complete destruction of Elevator A and the fact that the debris had not been completely cleared away while the investigators were on the ground made it impossible to determine the condition of equipment in which the explosion is believed to have originated. With the lines of propagation centering at the boot of Shipper 5, it is believed that this part of the grain-handling equipment was the point of origin, and the most probable cause of the initial ignition was foreign material entering the boot either from the cleaners or from the work floor.

Conclusions and Recommendations

All the elevators involved in this explosion and fire were of the old style wooden type, which made it impossible or impractical to comply with many of the suggestions in the terminal grain elevator safety codes. Unusual precautions had been taken for the prevention of fire, but this case demonstrated again that an elaborate sprinkler system can be rendered useless by an explosion. It is believed that it might have been possible to provide some protection in Elevators B and C if power could have been maintained at the fire pumps and control valves to cut out the damaged sections had been available. Where sprinkler systems are subject to the explosion

hazard, it is suggested that underground power lines to the pumps be provided and that remote control valves be installed to cut out damaged sections of sprinkler piping.

The increased use of motor trucks for the transportation of grain, and the hazards incident to their operation in dusty atmospheres, emphasize the need for further study of this problem. In some cases it is known that tilting of the truck to unload the grain may cause gasoline to spill from the tank of carburetor. After long runs with heavy loads the exhaust pipe and muffler of trucks may be hot enough to ignite dust. A backfire when the truck is started after unloading would be capable of igniting dust deposits around the dump. If this method of grain handling is used at an elevator, it is recommended that all possible precautions be taken to eliminate the sources of ignition mentioned.

The regulations which prohibit the application of suction before weighing grain entering an elevator prevent the elevator operator from providing adequate protection. Foreign material in grain received at an elevator is frequently of a type which may produce sparks if it enters the grain-handling machinery. Dust accumulated in the grain during previous handling operations must be received into the house with the grain and weighed. It is suggested that attention be given to the possibility of developing some system whereby dust removal during the handling of grain could be under supervision to prevent abuses. Dust could be caught in a bag and the bag included with the shipment where it is necessary to maintain weights. Some provision must be made to remove the incentive for elevator operators to return to the grain the dust removed during handling operations in order to maintain their incoming and outgoing weights. It will be necessary to develop and install effective methods for dust collection and dust control in grain elevators in order to reduce dust explosion losses in this industry. Until this is done it will not be possible to make progress in dust explosion control in terminal grain elevators comparable with what has been already accomplished in the control of the dust explosion hazard in other grain and milling industries.

(IX) Dust Control in Grain Elevators

It must be recognized that the most disastrous losses from dust explosions are occurring in terminal grain elevators and that satisfactory progress has not been made in the control of dust explosions in this branch of the grain-handling industry. Much of this can be assigned to the lack of provision for adequate dust control during handling, storing and shipping operations.

In considering this matter several years ago when it was apparent that extensive losses were occurring, the Bureau of Chemistry in the Department of Agriculture learned that many of the dust-collecting systems installed in grain elevators throughout the United States could not be used, or were dismantled because of the objection of the officials having jurisdiction over the weighing of the grain. The weighing departments stated that grain weights were greatly affected by the action of suction used in the collection of the dust. Reports of tests conducted by a number of elevator operators,

however, indicated that the weight of the dust removed is almost negligible. Some men experienced in grain handling stated that less dust is removed by suction than is lost in handling grain by means of poor machinery, with no dust collecting equipment.

Confronted with these conflicting statements, the Bureau of Chemistry made a preliminary study of the effects of dust collection on the weight of grain. The results of this study showed that much depended on the design and installation of the dust collecting equipment. In many cases the equipment seemed to have been installed with no knowledge of the fundamentals of good design. In some cases the claims of weighing departments that grain had been drawn out by improper application of suction to remove the dust at certain points between the car which was being unloaded and the scales were probably correct. No information concerning a generally accepted method of applying suction or the proper equipment to use could be obtained. Every elevator seemed to have its own system of dust control and no standards existed. None of the systems were so installed as to permit inspection, nor were they so designed that it would be impossible to lift grain by increasing the speed of the fan, with a corresponding increase of suction.

The results of these preliminary investigations showed the necessity for a detailed study of the problems of controlling dust conditions in grain elevators. U. S. Department of Agriculture Bulletin No. 1373 entitled, "Dust Control in Grain Elevators," by Hylton R. Brown and J. O. Reed, published in February, 1926 and revised in March, 1928 contains the results of these investigations.

Methods of Dust Control

The dust conditions in a grain elevator are effectively controlled only when:

(1) Dust clouds are eliminated at their point of origin by the application of suction.

(2) Dust accumulations are promptly removed from the building, either by a vacuum cleaning system or by a floor-sweep system.

(3) The elevator and equipment are well ventilated.

The mechanical methods of controlling dust conditions can be divided into; (1) dust collection; (2) dust removal; (3) ventilation.

(1) Dust collection deals with the methods of removing dust clouds at their source by means of induced air currents, supplied through specially designed hoods connected to a fan system.

(2) Dust removal deals with the methods of removing static dust, that is, dust which has settled and accumulated on the floors, walls, equipment, etc.

(3) Ventilation can be divided into natural ventilation and mechanical ventilation.

Dust Collection

Dust clouds rise at all points in the grain-handling system where grain is thrown, agitated or brought in contact with air currents. The principal points at which dust clouds are created in a grain elevator are: (1) at receiving or unloading pits; (2) at elevator boots; (3) in elevator heads and hoods; (4) at garners and scale hoppers; (5) at belt loaders; (6) at trippers; (7) at bins; (8) at discharges of conveyor belts; (9) at tails of conveyor belts; (10) miscellaneous points such as in marine towers in unloading boats, around turn heads or circle spouts on distributing floors or in basements and similar points of operation.

Dust Removal

Dust accumulations and deposits are removed from the floors, walls, ledges, and equipment of an elevator and conveyed to a central point of deposit outside the plant by a number of methods such as: (1) brush and broom method; (2) floor sweep systems; (3) compressed air; (4) vacuum cleaning systems.

Natural Ventilation

Natural ventilation can be accomplished by: (1) doors; (2) windows; (3) louvers; (4) stationary roof ventilators; (5) revolving roof ventilators; (6) pressure ventilators; (7) floor ventilators; (8) interstice bin ventilation of basement.

Mechanical Ventilation

Mechanical ventilation can be accomplished by: (1) disc ventilating fans; (2) interstice bin fans.

Dust Control Equipment

Dust control equipment in grain elevators includes: (1) fans; (2) piping system; (3) dust collectors; (4) grain traps; (5) suction regulators; (6) inspection traps; (7) air velocity control valves.

Effect of Suction on Grain Weights

Observations have been made by various agencies in grain elevators in various parts of the United States to determine what effect the use of suction as applied by dust collecting equipment may have on grain weights.

(1) Tests were conducted by the Bureau of Chemistry, U. S. Department of Agriculture, in an export elevator equipped with a dust collecting system that applied suction to the scale hoppers, garners, belt loaders, and boots. One of the scale hoppers was filled with No. 2 hard wheat and

weighed. The grain was then dumped and spouted into a storage bin from which it was later transferred to a shipping belt to be elevated for reweighing. Four runs were made - two with suction and two without suction. The garner bin was swept clean before each weighing, and the first weight of each run was taken under the same conditions as the last weight of the preceding run. Four suction lines not connected at hoods acted directly on the grain: (1) a 3-inch pipe connection at the belt loader; (2) a 3-inch pipe at the elevator boot; (3) a 6-inch line to the garner bin; and (4) a 6-inch connection to the scale hopper.

The results of these tests can be summarized as follows:

(1) The shrinkage losses varied whether suction was used or not.

(2) On the whole, the shrinkage loss was slightly greater when the fans were not operating than when they were running.

(3) In two of the tests, when the fans were operating, the total shrinkage was 140 lbs. for a total weight of 232,600 lbs., or about 1/16 of one percent.

(4) In the other two tests when the fans were not operating, the loss was 180 pounds in a total weight of 232,700 lbs. - about 1/13 of one percent.

(5) The largest shrinkage loss of 140 lbs. occurred in one of the tests when the fans were not running.

(6) The results indicate that the effect on grain weights when suction is applied is practically the same as in the normal handling of grain without dust collecting equipment.

(2) Preliminary investigations have also been conducted by the Bureau of Chemistry in a number of grain elevators to determine the quantity of dust collected while elevating carlots of grain. The results of these tests can be summarized as follows:

(a) Tests on 39 cars showed an average of 7 1/2 pounds of dust collected per car. Several cars in this lot contained very dusty oats and several others contained screenings.

(b) An average of 19 pounds of dust per car was removed from four cars of No. 3 white oats.

(c) In spite of the fact that these tests were made with 1918 equipment which was not so designed that at all fan speed it would be impossible to lift heavy particles from the moving grain stream, the quantity of dust gathered by the dust collecting system probably would not exceed the natural loss incurred without dust collecting equipment.

(3) Tests conducted by the Minnesota Railroad and Warehouse Commission in an elevator equipped with a dust collecting system designed and installed

so that only the light floating dust was removed, showed the following results:

(a) During the unloading of a car containing 50,000 pounds of flax screenings, 13 1/2 pounds of dirt, refuse and fibrous material was collected - 1/33 of one percent.

(b) In the unloading of another car containing 50,000 lbs. of No. 2 northern wheat only 25 1/2 ounces of dust was collected - 1/300 of one percent.

These two tests were conducted on the extreme grades of material handled in a terminal grain elevator.

(4) During the last year a large industrial plant in the Middle West handled approximately 1,791,250 bushels of corn with a moisture content of 16.49 percent. There were 1,250 bushels of screenings removed - 56 lbs. per bushel equals 70,000 lbs. This amounts to only 7/100 of one percent in weight.

Control of Floating Dust in Terminal Grain Elevators

In 1923 and 1924 Underwriters' Laboratories, Inc. conducted investigations to determine the essential factors involved in the application of suction to belt loaders, belt discharge pulleys, elevator heads, garners and similar parts of grain-handling equipment in order to minimize the escape of floating dust into the atmosphere of the elevator and at the same time accomplish this object without picking up an appreciable quantity of solid grain.

In these investigations the following problems were studied at a number of terminal elevators in Minneapolis:

(1) What maximum air velocity should be allowed at dust hoods to properly care for the dust without drawing in solid grain?

(2) What minimum air velocity in branch pipes and trunk lines will carry the dusty air and refuse from floor sweeps without allowing any particles to settle out and clog the lines?

(3) The feasibility of locating inspection traps in pipe lines near suction hoods, to be used by inspectors when checking the performance of the system, enabling them to determine whether grain is removed through the dust system.

(4) Application of direct versus indirect suction. By "direct connection" is meant a hood tightly attached to a boot, a garner, or other equipment, and to which the suction pipe is tightly attached. "Indirect connections" usually have the hood near, but not connected directly to the enclosed equipment.

Results of the Investigations

The findings of this investigation can be summarized as follows:

(1) To prevent the pick-up of solid grain, the average air velocity at the intakes of suction hoods should be limited to 500 ft. per minute.

(2) The average air velocity in suction pipe lines should be at least 3,600 ft. per minute to prevent the clogging of the lines by the settling of materials likely to enter the system. This is especially important in view of the frequent connection of floor sweeps and dust hoods to the same trunk line piping.

(3) A definite ratio exists between hood-intake velocity and pipe line velocity. In the usual type of installation this relation is expressed as a ratio of hood intake area to pipe area. Any pipe line velocity in excess of 3,600 feet per minute may be employed, provided the hood area is large enough to limit the intake velocity to 500 feet per minute.

(4) As compared with direct connections, indirect connections are not effective in removing or controlling floating dust.

(5) Inspection traps may be installed in branch pipe lines at convenient locations permitting determination by inspection that solid grain is not being carried away by the dust removal system.

Conclusions

The following conclusions can be arrived at as the result of these investigations.

(1) Effective systems can be designed for dust control in grain elevators without affecting grain weights.

(2) These systems should be under supervision of competent inspection authorities.

(3) Further research will be instrumental in working out the essential engineering features of the problem.

It will be necessary to develop and install effective methods for dust control and collection in grain elevators to reduce dust explosion losses. Until this is done, it will not be possible to make progress in dust explosion control in terminal grain elevators comparable to what has been accomplished in the control of dust explosions in other grain and milling industries.